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(54) **Determining the torque applied by a motor or engine to a rotating load**

(57) For the determination of the torque which is applied by a motor 1 or an i.c. engine to a rotating load 4, the change of the motor driving moment in dependence on the value of a measurable operational parameter, such as the motor current of an electric motor, measured at 5 in Figure 2, or the intake pressure of an i.c. engine, is stored in a memory 13; speeds are measured e.g. by counters 8, 9 after predetermined intervals of time controlled by a clock 10, the difference between each two consecutive speed measurements, is formed at 11 and is divided by the predetermined interval of time at 12, the resulting quotient is multiplied by a factor which is proportional to the total moment of inertia, the motor driving moment corresponding to the instantaneous value of the operational parameter being read from the memory 13, and the product obtained by the multiplication by the above-mentioned factor is subtracted from said instantaneous value at 14.
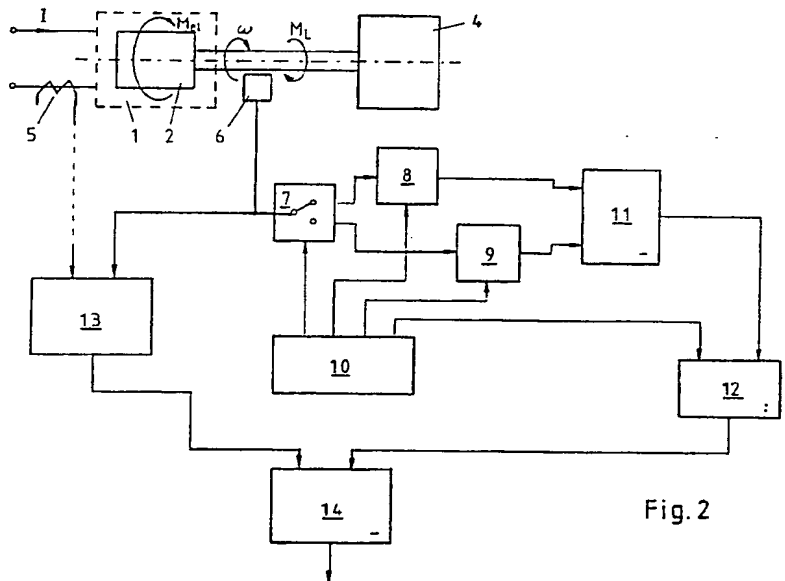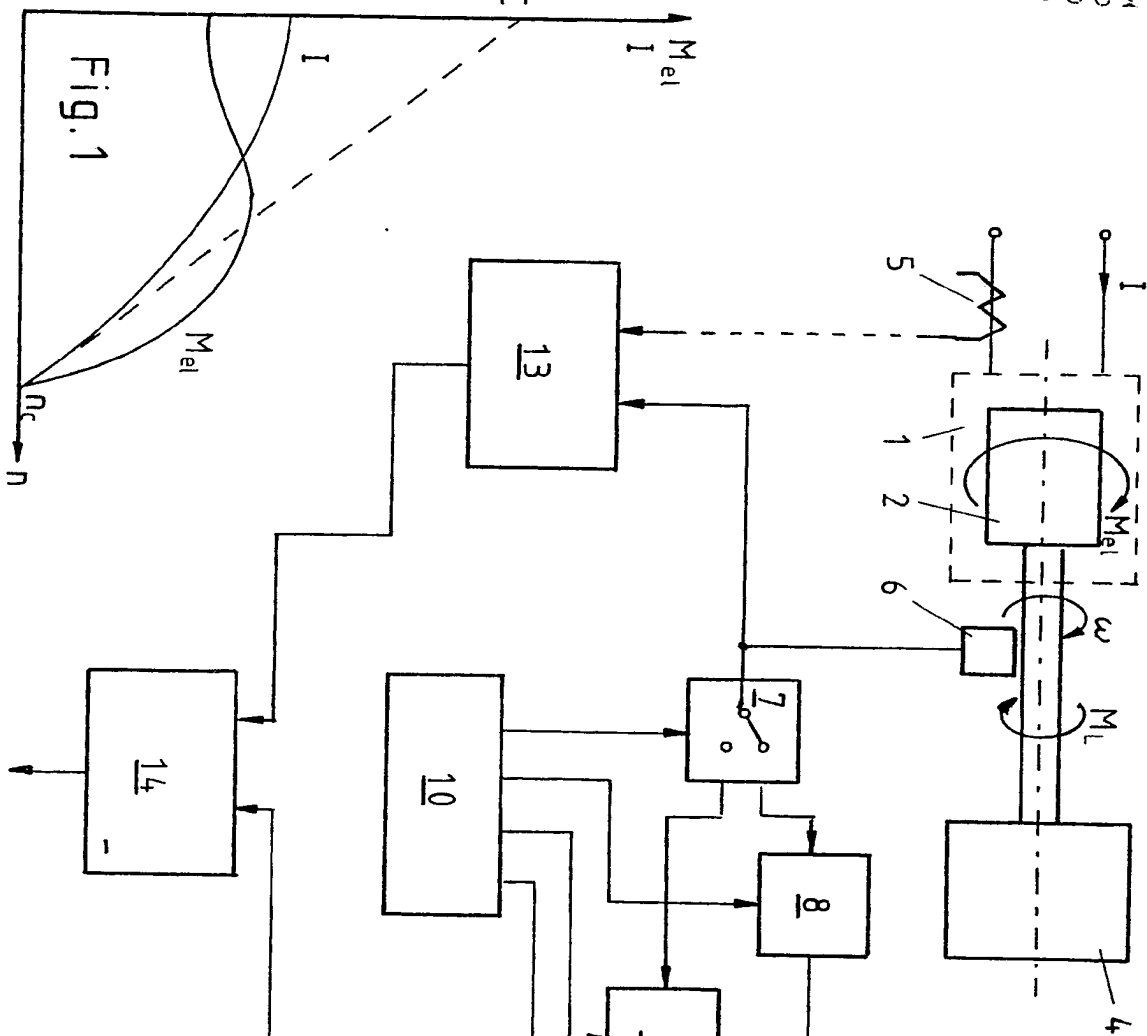

Fig. 2

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Fig.1

M_{el}, I

M_{el}

I

C

n_c

n

Fig.2

M_{el}

I

5

1
2

M_{el}

6

ω

M_L

4

13

7

10

8

9

14

11

12
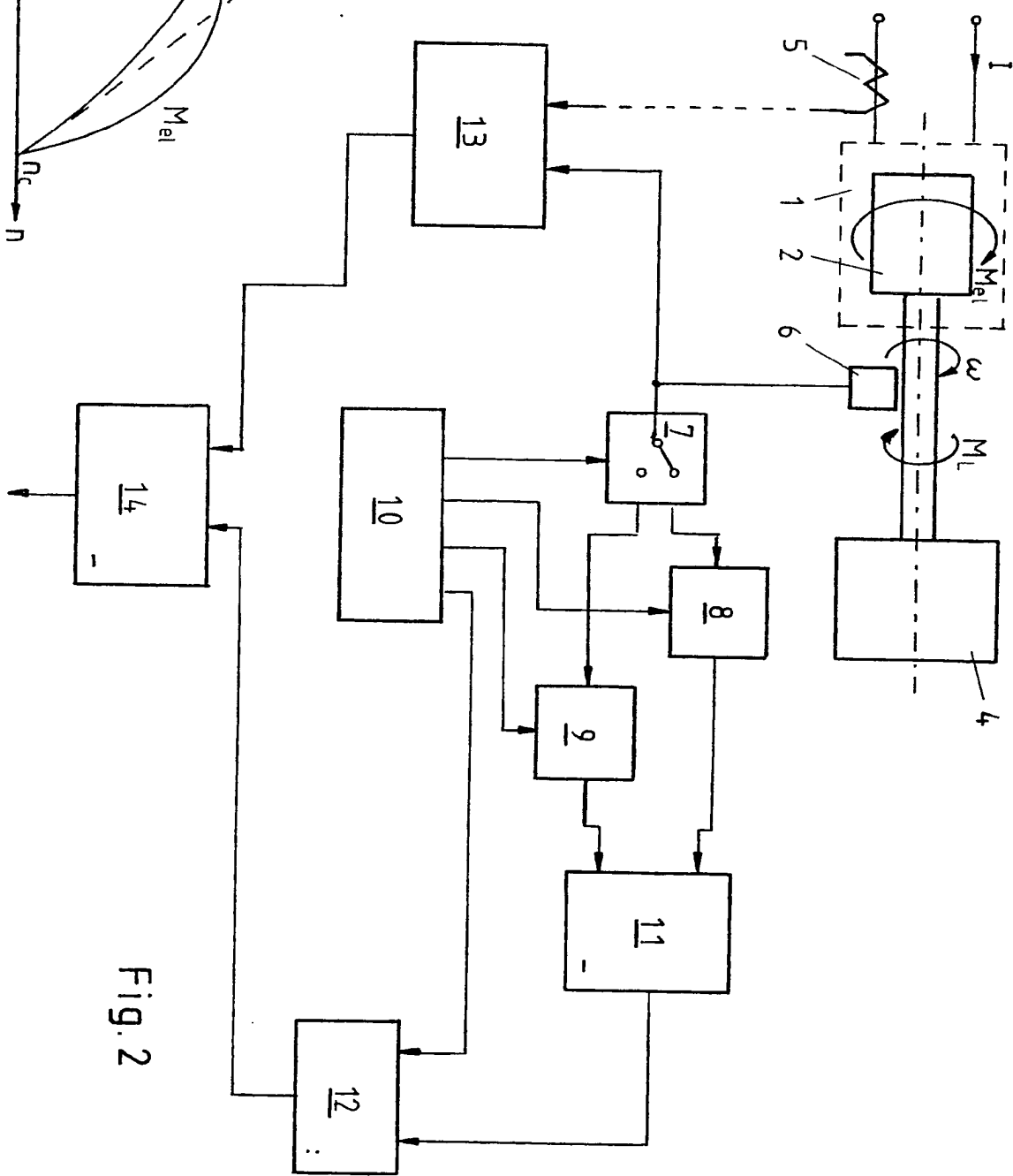
terminals of which are connected to the input terminals of two buffer memories, a clock for delivering timing
signals is associated with the change-over switch and the buffer memories, two multipliers are provided,
which have first input terminals, each of which is connected to one output terminal of an associated buffer
memory, and second input terminals for receiving respective signals, which represent the first and second
5 weighting factors, respectively, the output terminals of the mutlipliers are connected to the two input   5
terminals of the subtracter, and an adder is provided, which has one input terminal that is connected to the
output terminal of the subtracter and another input terminal for receiving a signal which represents a
constant factor.

In such an arrangement the speed pickup may desirably comprise in known manner a pulse generator and
10 a pulse counter, which succeeds the pulse generator and is controlled by the clock.   10

The invention with further advantage and features will now be explained more in detail with reference to
illustrative embodiments shown on the drawing, in which Figure 1 is a graph illustrating the dependence of
the electric moment and of the current of an electric motor on speed, Figure 2 is a diagrammatic view
illustrating an arrangement in accordance with the invention for determining the load moment, and Figure 3
15 shows another arrangement in accordance with the invention for determining the load moment.   15

The invention is based on the assumption that it is generally possible to state a fixed relation between the
moment driving a motor and the measurable value of an operational parameter of that motor. With
reference to an illustrative electric motor, Figure 1 illustrates the dependence of the driving electric moment
M_{el} on speed n. The graph indicates also the change of the motor current I as a function of speed. It is
20 apparent that a certain electric moment M_{el} can clearly be associated with the motor current or with the   20
speed, which are operational parameters that can easily be measured. Similar remarks are applicable to
different motors, such as internal combustion engines or hydraulic motors, in which the driving moment
may be associated, e.g., with the intake pressure or the hydraulic pressure.

Figure 2 is a diagrammatic view showing an electric motor 1 having a rotor 2 which by means of a shaft 3
25 drives a rotating load 4. The input current I of the motor 1 can be measured by means of a current sensor 5   25
and the speed n of the motor can be measured by means of a speed pickup 6.

The invention is concerned with the determination of the load moment M_L which is transmitted via the
shaft 3 to the load 4. The moments which occur are related in accordance with the following equation:

$$M_L = M_{el} + \ddot{y}^{\Theta} R \qquad (1)$$

30

wherein

M_{el} .....   electric moment driving the motor
35 $\ddot{y}$ .....   angular acceleration   35
Θ_R .....   moment of inertia of the rotating masses

In equation (1), M_{el} will be known from the characteristic of the motor if the speed is known. Θ_R is a
constant of the system and $\ddot{y}$ can be derived from a measured speed because
40   40

$$\ddot{y} = \dot{\omega} = \frac{\pi}{30} \cdot \frac{dn}{dt} \qquad (2)$$

45 As will also be shown in the illustrative embodiment, these values can be determined by a measurement   45
of two speeds n_1, n_2 at the beginning and end of an interval of time Δt and by the following division:

$$\frac{dn}{dt} = \frac{n_2 - n_1}{\Delta t} \qquad (3)$$
50

For this reason the arrangement shown in Figure 2 comprises a change-over switch 7, having an input
terminal that is connected to the speed pickup and having output terminals connected to the input terminals
55 of buffer memories 8, 9 controlled by a clock 10 so that the speed can be measured after predetermined   55
intervals of time and the difference between said speeds can be divided by the interval of time. For instance,
the speed n_1 is measured at a certain time and is stored in the memory 9. The speed n_2 is measured after the
interval of time Δt and is stored in the memory 8. The values n_2, n_1 are delivered to a subtracter 11, which
computes the difference $(n_2 - n_1)$. The output terminal of the subtracter 11 is connected to one input terminal
60 of a divider 12, which at its other input terminal receives from the clock 10 a signal which represents the time   60
Δt. As a result, the signal appearing at the output terminal of the divider represents $(n_2 - n_1)/\Delta t$ or that
quantity multiplied with the factor $\pi/30$.

The characteristic plotting M_{el} against speed n or motor current I has been stored in the memory 13. For
this reason the signal M_{el} appearing at the output terminal of the memory 13 will be related to the
65 instantaneous motor current I measured by the current sensor 5 or to the speed n measured by the speed   65

pickup 6. The output terminal of the memory 13 is connected to one input terminal of a second subtracter 14, which at its other input terminal is connected to the output terminal of the divider 12 so that the signal $M_L = M_{el} - \ddot{y}\Theta_R$ which is to be determined appears at the output terminal of the subtracter 14.

Figure 1 shows a straight line, which approximately represents the change of the electric moment M_{el} in a
5 certain speed range. For this reason the electric moment can be represented by

$$M_{el} = C - \frac{C}{n_c} \cdot n(t) \tag{4}$$

10 For n = n_2, the last-mentioned equation together with equations (1) and (3) gives the result

$$M_L = C + n_1 \cdot \frac{\pi}{30} \cdot \frac{\Theta_R}{\Delta t} - n_2 \left(\frac{C}{n_2} - \frac{\pi}{30} \cdot \frac{\Theta_R}{\Delta t} \right) \tag{5}$$

15 If the measuring interval Δt is always the same, equation (5) can be written as follows:

$$M_L = C + n_1 k_1 - n_2 k_2 \tag{5'}$$

20 wherein

$$k_1 = \frac{\pi}{30} \cdot \frac{\Theta_R}{\Delta t} \quad \text{and} \quad k_2 = \left(\frac{C}{n_c} - \frac{\pi}{30} \cdot \frac{\Theta_R}{\Delta t} \right) \tag{6}$$

25 On the basis of the simplified explanation given above, the load moment can be determined by means of the arrangement shown in Figure 3.

In accordance with Figure 3 a pulse generator 15 is provided on the shaft 3 or at another rotating member of the system comprising the motor 1 and the load 4. In known manner the pulse generator 15 generates
30 pulses at a rate which is proportional to speed. The output terminal of the pulse generator is connected to the input terminal of a counter 16, which is controlled by a clock 17. For a predetermined time the counter 16 counts the pulses, the number of which is a measure of speed. The output terminal of the counter 16 is connected to the input terminal of a change-over switch 18. It is mentioned at this juncture that the speed can be determined by a different method, e.g., by an analog method as illustrated in Figure 2.
35 The two output terminals of the change-over switch 18 are connected to the input terminals of buffer memories 19, 20, which just as the change-over switch 18, are controlled by the clock 17. The change-over switch 18 and the memories 19, 20 are controlled in such a manner that speeds n_1, n_2 etc. measured after respective intervals of time Δt are stored in the memories 19, 20 in alternation and are available at their output terminals. The output terminal of each of the memories 19, 20 is connected to one input terminal of an
40 associated one of the multipliers 21, 22, which at their input terminals receive signals representing the constants k_1 and k_2, respectively, of equation (6).

The products $n_1 k_1$ and $n_2 k_2$, respectively, appear at the output terminals of multipliers 21, 22. Said output terminals are connected to the two input terminals of a subtracter 23 so that the signal $(n_1 k_1 - n_2 k_2)$ appears at the output terminal of the subtracter 23 and is delivered to one of the input terminals of the adder 24,
45 which at its other input terminal receives a signal that represents the constant (C) in equation (4) or (5) so that the signal M_L to be determined appears at the output terminal of the adder and is delivered to a display 25 or the like.

CLAIMS
50

1. A method of determining the load moment which is applied by a motor to a rotating load, wherein the differential quotient of angular velocity with respect to time is derived from speed measurements and is multiplied with a factor that is proportional to the total moment of inertia and the resulting value is subtracted from a motor driving moment that corresponds to the instantaneous value of a measurable
55 operational parameter, characterized in that the change of the motor driving moment in dependence on the value of the measurable operational parameter, such as the speed, the motor current of an electric motor, or the intake pressure of an internal combustion engine, is stored in a memory, and the instantaneous motor driving moment is read from the memory for the measurement.

2. A method of determining the load moment which is applied by an electric motor to a rotating load,
60 wherein the speeds are measured after predetermined intervals of time, characterized in that the first measured speed is multiplied with a first weighting factor, the second measured speed is multiplied with a second weighting factor, the resulting second weighted speed is subtracted from the first weighted speed and a constant corresponding to the motor driving moment at zero speed is added to the resulting
65 difference.

3.   A method according to claim 1, characterized in that the multiplication of successively measured speeds with the weighting factors is effected by a counting of the speed-proportional pulse rate for respective counting times, which are proportional to the weighting factors.

4.   An arrangement for carrying out the process according to claim 1, characterized in that the output 5 terminal of a speed pickup (6) is connected to the input terminal of a change-over switch (8), both output terminals of which are connected to the input terminals of two buffer memories (8, 9), a clock (10) is provided, which is arranged to deliver timing signals (t) and has output terminals respectively connected to the control input terminal of the change-over switch (7) and to the control input terminals of two memories (8, 9) which are adapted to be read in alternation and have output terminals connected to the two input 10 terminals of a first subtracter (11), a divider (12) is provided, which has one input terminal connected to the output terminal of the subtracter (11) and another input terminal for receiving a signal (t) from the clock (10), a characteristics memory (13) is provided, in which the change of the motor driving moment (M_{el}) as a function of the value of a measurable operational parameter, such as speed (n), is stored, and which has a readout input terminal for receiving the value of that operational parameter, the instantaneous value of the 15 motor driving moment appears at the output terminal of the characteristics memory (13), and a second subtracter (14) is provided, which has a first input terminal connected to the output terminal of the characteristics memory and a second input terminal connected to the output terminal of the divider (12).

5.   An arrangement according to claim 4, wherein the motor is an electric motor, characterized in that a motor current sensor (5) is provided and has an output terminal that is connected to the input terminal of the 20 characteristics memory (13).

6.   An arrangement for carrying out the method according to claim 2, characterized in that the output terminal of a speed pickup (15, 16) is connected to the input terminal of a change-over switch (18), both output terminals of which are connected to the input terminals of two buffer memories (19, 20), a clock (17) for delivering timing signals (Δt) is associated with the change-over switch (18) and the buffer memories (19, 25 20), two multipliers are provided, which have first input terminals, each of which is connected to one output terminal of an associated buffer memory (19, 20), and second input terminals for receiving respective signals (k_1, k_2) which represent the first and second weighting factors, respectively, the output terminals of the multipliers are connected to the two input terminals of a subtracter (23), and an adder (24) is provided, which has one input terminal that is connected to the output terminal of the subtracter (23) and another input 30 terminal for receiving a signal (C) which represents a constant factor.

7.   An arrangement according to claim 6, characterized in that the speed pickup comprises in known manner a pulse generator (15) and a pulse counter (16), which succeeds the pulse generator (15) and a pulse counter (16), which succeeds the pulse generator and is controlled by the clock (17).

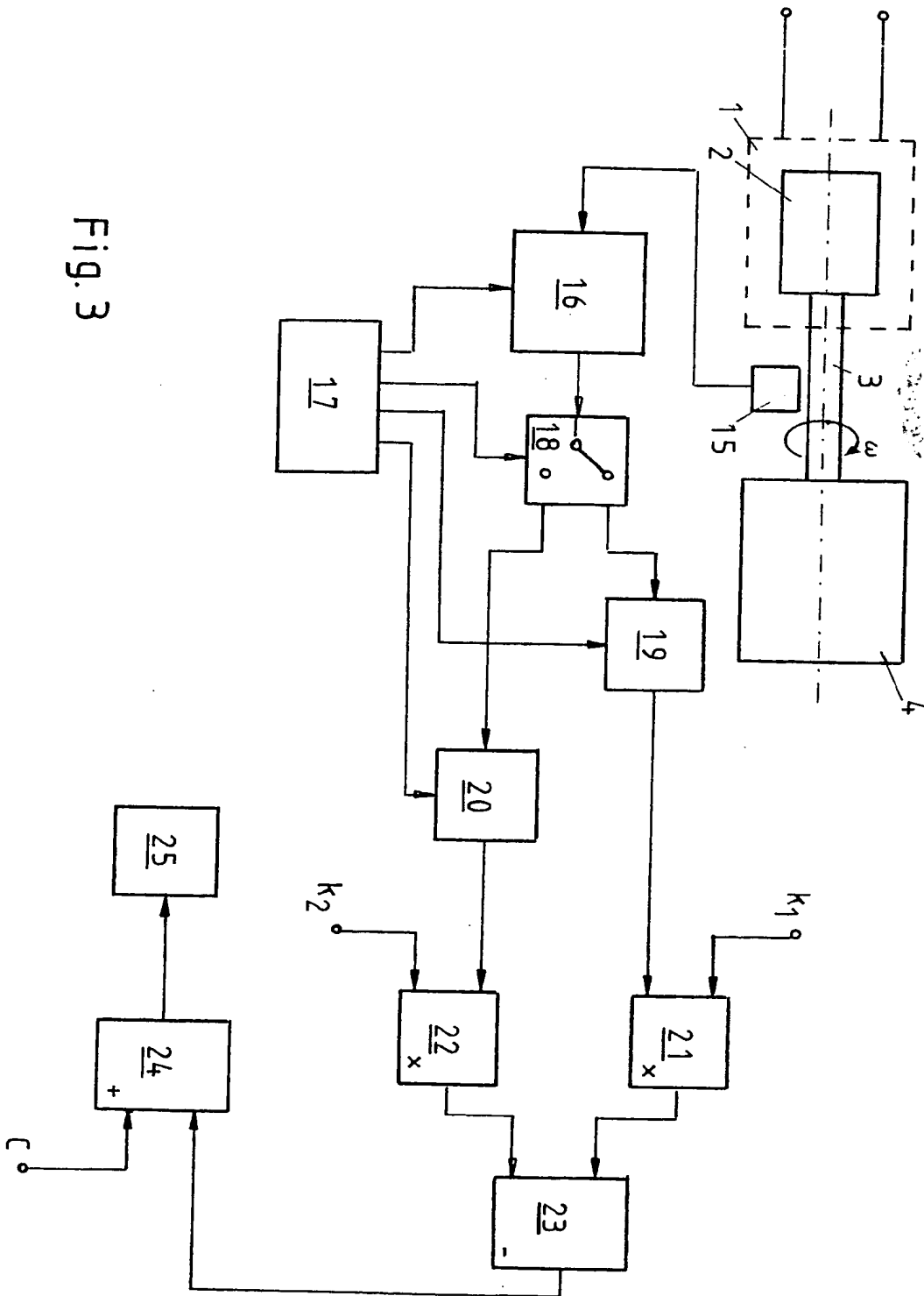THIS PAGE BLANK (USPTO

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Fig.3

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SPECIFICATION

Method of determining the load moment which is applied by a motor to a rotating load

5   This invention relates to a method of determining the load moment which is applied by a motor to a rotating   5
load, wherein the differential quotient of angular velocity with respect to time is derived from speed
measurements and is multiplied with a factor that is proportional to the total moment of inertia and the
resulting value is subtracted from a motor driving moment that corresponds to the instantaneous value of a
measurable operational parameter.

10   It is often desired to ascertain by measurement the torque of rotating shafts in order to obtain information   10
on the instantaneous load conditions. Various measuring setups for that purpose have been disclosed, e.g.,
strain gauges which are provided at the rotating shaft and permit a determination of torque as a function of
the measured torsional stress. By means of the known methods it is often impossible or highly expensive to
determine the torque, for instance, because the shaft concerned is not accessible or because the measuring
15   instruments used are not sufficiently robust.   15
In a known method of the kind described first hereinbefore (Published German Application 27 02 981) the
armature current of a d.c. motor is measured and is multiplied with a constant so that a signal is obtained
which represents the maximum moment associated with a full exciter field. In conjunction with motors
operating under frequently changing conditions that method will provide only relatively inaccurate values
20   and the method cannot be used at all with other motors, such as internal combustion engines.   20
For a monitoring of the capacity of an internal combustion engine it is known from Published German
Application 31 03 648 that the average torque can be determined by a method in which the times between
occurrence of speeds at two speed thresholds are measured in a run-up test and a coasting test. The average
torque can be calculated from said times in accordance with a known formula. But the instantaneous torque,
25   which is often interesting, cannot be determined in that manner.   25
It is an object of the invention to provide a method and an arrangement by which the instantaneous torque
which is applied by a motor to a rotating load can be very exactly determined in a simple and reliable
manner.
In a method of the kind described first hereinbefore that object can be accomplished in accordance with
30   the invention in that the change of the motor driving moment in dependence on the measurable value of the   30
operational parameter, such as the speed, the motor current of an electric motor, or the intake pressure of an
internal combustion engine, is stored in a memory and the instantaneous motor driving moment is read
from the memory for the measurement.
The method in accordance with the invention affords the advantage that a measurement of speeds at
35   successive times is sufficient for a determination of the instantaneous load moment. An analog   35
measurement of speed can always be effected by known methods, even under difficult conditions.
In a method of determining the load moment applied by an electric motor to a rotating load in such a
manner that the speeds are measured after predetermined intervals of time, it will be desirable to multiply
the first measured speed with a first weighting factor and to multiply the second measured speed with a
40   second weighting factor, whereafter the resulting second weighted speed is subtracted from the first   40
weighted speed and a constant corresponding to the motor driving moment at zero speed is added to the
resulting difference. That method is based on the assumption that the dependence of the electric moment
driving an electric motor on speed can be represented in many cases with adequate accuracy as a straight
line so that there is no need for characteristics memory.
45   In such case the method may be simplified in that the multiplication of successivly measured speeds with   45
the weighting factors is effected by a counting of pulses at a speed-proportional pulse rate for respective
counting times, which are proportional to the weighting factors.
In a desirable arrangement for carrying out the method in accordance with the invention the output
terminal of a speed pickup is connected to the input terminal of a change-over switch, both output terminals
50   of which are connected to the input terminals of two buffer memories, a clock is provided, which is arranged   50
to deliver timing signals and has output terminals respectively connected to the control input terminal of the
change-over switch and to the control input terminals of the two memories, which are adapted to be read in
alternation and have output terminals connected to the two input terminals of a first subtracter, a divider is
provided, which has one input terminal connected to the output terminal of the subtracter and another input
55   terminal for receiving a signal from the clock, a characteristics memory is provided, in which the change of   55
the motor driving moment as a function of the value of a measurable operational parameter, such as speed,
is stored, and which has a readout input terminal for receiving the value of that operational parameter, the
instantaneous value of the motor driving moment appears at the output terminal of the characteristics
memory, and a second subtracter is provided, which has a first input terminal connected to the output
60   terminal of the characteristics memory and a second input terminal connected to the output terminal of the   60
divider.
If the motor of such arrangement is an electric motor, it may be desirable to provide a motor current
sensor having an output terminal which is connected to the input terminal of the characteristics memory.
In a desirable arrangement for carrying out a modified method of the kind described hereinbefore, the
65   output terminal of a speed pickup is connected to the input terminal of a change-over switch, both output   65